METAL MESH FILTERS FOR INFRARED APPLICATIONS

Oren Sternberg*, Jacqueline Fischer, Kenneth P. Stewart, Milton L. Rebbert
Naval Research Laboratory, Washington DC

Karl D. Möller, Haim Grebel
Electronic Imaging Center, New Jersey Institute of Technology, Newark, NJ

Howard Smith
Center for Astrophysics, Harvard Smithsonian, Cambridge, MA

Rainer Fettig
Institut f. Mikrostrukturtechnik, Forschungszentrum Karlsruhe, Germany

ABSTRACT

The transmittance peaks of inductive and capacitive metal meshes have been assigned to a number of modes and their interaction. Single thin meshes show resonance modes depending on the periodic structure of the mesh and slab modes when in touch with dielectric layers. Two and four meshes show stacking modes depending on separation similar to photonic crystals.

INTRODUCTION

Infrared filters play an integral role on every infrared astronomy airborne and/or space mission. They isolate the desired infrared signal from more energetic short wavelength radiation, allow color temperature measurements, provide order sorting for grating spectrometers, and improve the signal-to-noise for Fourier transform spectrometers. The need for such devices is critical now, as space astronomy in particular begins to emphasize far infrared research programs in the new millennium. At the same time, only in the past few years has the technology been available to design and fabricate these nanotechnology filters: the new computer codes, which have been used, are able to calculate precise electromagnetic solutions for filter designs, while modern nano-technology facilities are available for fabrication.

Metal mesh filters work on fundamentally different principles than multi-layer dielectric filters, and suffer none of the problems of dielectric coatings. By understanding the resonance behavior of metal-dielectric meshes as well as the various near field effects, one can further develop the design theory for these components and fabricate better and new devices. Among these are bandpass and low (or high) pass filters and dichroic or polarizing beamsplitters.

Metal Meshes

Inductive cross shaped metal meshes are made of thin metal foils with cross shaped openings. The inverse structure is called capacitive mesh. Babinet's principle in vector formulation states that complementary screens have complementary transmittance. This is shown in Figure 1 for inductive and capacitive free standing mesh. One observes a maximum for the inductive mesh and a minimum for capacitive mesh. The incident light excites a standing wave on the surface of the mesh, and transfers the incident energy into reflected and transmitted light[1].

* *Contact information for Oren Sternberg Email: Oren.Sternberg@nrl.navy.mil , phone: 202-767-0043*

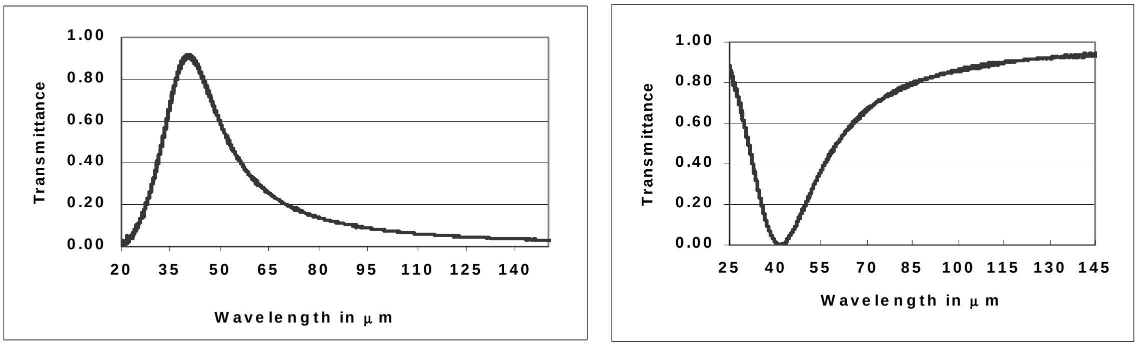


Figure 1*: Transmittance through inductive (left) and capacitive (right) metal meshes (periodicity constant of 20μm). The resonance wavelength is the same for thin complementary inductive and capacitive meshes*

Resonance and Stacking Modes of Two Meshes at a Separation S

In Figure 2 we show two meshes at a separation S. The incident light excites resonance modes of wavelength λ_R. When changing the separation of the meshes from S=0 to larger values, a new mode shows up with wavelength λ_S. This "stacking mode" will also appear when more than two meshes are stacked up and have the same separation S. Depending on the separation S, the resonance mode and the stacking mode will interact in the same manner two oscillators do. Figure 3 shows that the "non crossing rule" is obeyed when the wavelength λ_S approaches the value of $\lambda_{R.}$[2]

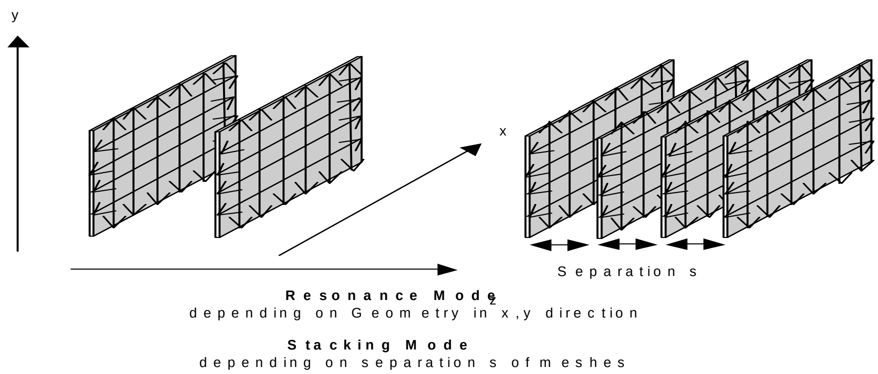


Figure 2: *Two and four metal meshes at same separation S. There is the resonance mode of the single mesh and the Stacking Mode depending on the separation. Both modes interact when the stacking mode approaches the resonance mode*

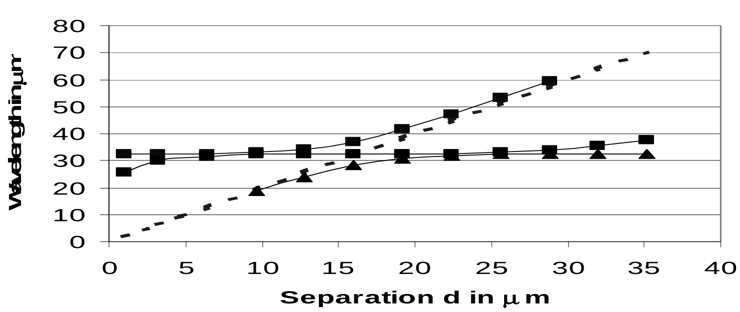


Figure 3: *Interaction of resonance (squares) and Stacking Modes (triangles) for two meshes depending on separation S. The "non crossing rule" applies at about ½ of the resonance wavelength*

Aligned Meshes and Photonic Crystals

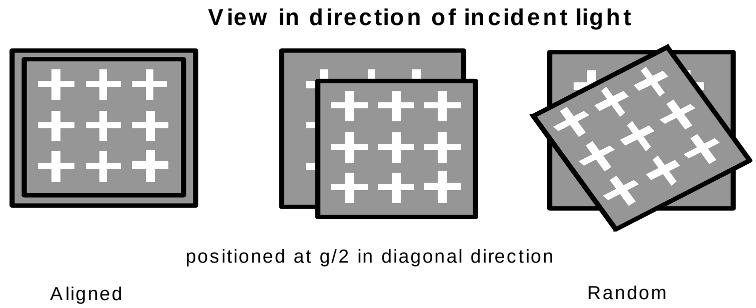


Figure 4: *Schematics of positioning of two meshes: "aligned", "non aligned/shifted", and "random"*

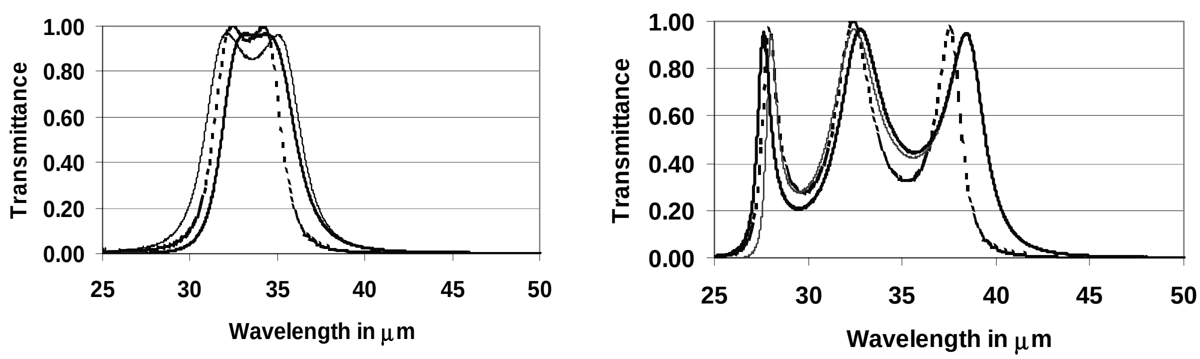


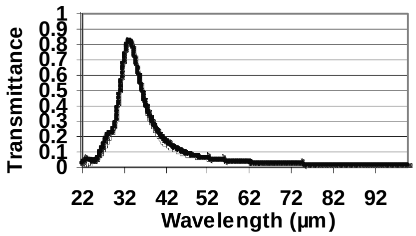
Figure.6: *Two metal meshes at separation s. Single mesh: Resonance wavelength at 32.4mμ. Geometrical parameters: g = 24mμ, 2a = 9.6mμ, 2b = 3.6mμ. Thickness 0.2mμ. Two meshes :Bold solid line: aligned. Solid line: shifted. Broken line: Random.*
b) Separation at 1/4 of resonance wavelength, Minimum interaction of resonance and stacking mode, only resonance modes are shown..
c) Separation at 1/2 of resonance wavelength, Maximum interaction of resonance and stacking mode, resonance modes at longer and stacking mode at shortest wavelength.

Experimental and simulated results of metal mesh with dielectrics

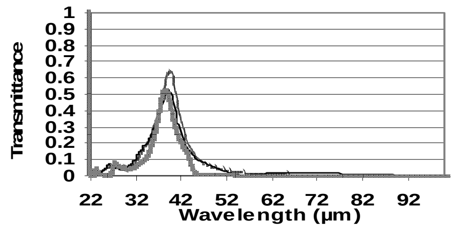
The experimental results of metal meshes with dielectrics agree very well with simulated results, as seen in Figure 7. When a metal mesh is on top of a thick dielectric substrate the resonance peak length will shift by a factor [6] expressed below

$$0.5(n_1^2 + n_2^2)^{0.5} \qquad (1)$$

However, when the thickness of the substrate is decreased the shift will be reduced. In Figure 7(a) we show a cross shaped mesh with a thin layer of polyimide. In Figure 7(b) we show a "hybrid" type metal mesh filter with a stucture of a few layers of inductive and capacitive meshes.[3-6]



(a)



(b)

Figure 7: *Metal mesh with dielectric. (a) cross shaped metal mesh with thin dielectric measurement bold line, simulated thin line. (b) 38μm filter mesh gray simulated, dark line 298K, light gray cold 5K. simulated.*

Summary

The transmittance of two cross shaped metal mesh filters can be described by the interaction of resonance and stacking modes, with a near field effect apparent for small distances. At a spacing of $\lambda_R/4$, as expected from oscillator theory, two meshed filters show just one peak, indicating minimum interaction of the modes. Four layers of aligned meshes (photonic crystals) show a more square like shape of transmittance. The resonance wavelength and bandwidth of a single mesh in contact with dielectric layers, calculated with electromagnetic theory, shows a wavelength shift of the resonance to longer wavelength. The interpretation, using the oscillator model, is in simple terms: the incident light excites a compound mode of mesh and dielectric. This excited mode is composed of a standing wave with wave vector $k = 0$ and transfers the energy to the reflected and transmitted light. The stacking modes depend on the separation of the oscillators and have a wave vector parallel to the incident light. Simulations using electromagnetic theory, verified by experimental observations, show that filters with a width of 10-20% and 80-90% transmittance can be made in the Mid and Far IR wavelength region.

Acknowledgements

The research has been sponsored by the remote sensing division of Naval Research Laboratory. Some of this research has been performed while the O. Sternberg held a National Research Council Research associateship award at Naval Research Laboratory.

REFERENCES

1. O. Sternberg *Resonances of Periodic Metal-Dielectric Structures in the Infrared Wavelength Region*, Thesis Advisor: Dr. K.D Möller, 2002.
2. K. D. Möller, Oren Sternberg, Haim Grebel, and Kenneth P. Stewart, *Near- field effects in multilayer inductive metal meshes*, Applied Optics, 41, 1942-1948, 2002.
3. K. D. Möller, Oren Sternberg, Haim Grebel, and Kenneth P. Stewart*Inductive cross-shaped metal meshes and dielectrics,* Applied Optics, 41, 3919, 2002.
4. O. Sternberg, K.D. Möller, H. Grebel, K.P. Stewart, R.M. Henry, *Inductive Cross-Shaped Metal Meshes on Silicon Substrate*, Journal of Infrared Physics, 44**,** 17-25, 2003.
5. H. Smith, M. Rebbert, and O. Sternberg., *Designer infrared filters using stacked metal lattices*, Applied Physics Letters, 82, 21 3605-3607, 2003.
6. T. Timusk and P. L. Richards, *Near Millimeter wave band-pass filters*, Applied Optics, 20, 1355-1360, 1981.
7. R. Ulrich, K.F. Renk, and L. Genzel, *Tunable submillimeter interferometers of the Fabry-Perot type*, IEEE Trans. Micro-wave Theory Tech, MTT-11, 363-371, 1963.
8. Micro-Stripes Program Ver 6.0, [Computer Software], (2002), Southborough, Massachusetts: Flomerics